Macomb County Site Evaluation Tool
Model Documentation

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Prepared by

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1 Introduction

The Site Evaluation Tool (SET) is a Microsoft Excel spreadsheet, and is designed to aid in the assessment of development plans and available Best Management Practices (BMPs) to achieve water quality objectives.

This document discusses the underlying models and methodologies used in the Macomb County SET. It provides details on key assumptions used by the SET, including parameters used to calculate pollutant loads, BMP pollutant removal efficiencies, methods used to calculate Macomb County's Stormwater Criteria for Water Quality Volume (WQv) and Channel Protection Volume (CPv), and calculations for implementing Stormwater Credits for reducing the required WQv and CPv. A separate User's Manual and Guidance document (Tetra Tech, 2010a) is also available for this tool. The User's Manual discusses in detail the use of the SET, includes screen shots and descriptions of required inputs, and gives an example of its application. More information about the Stormwater Criteria and Credits can be found in Macomb County's *Procedures and Design Standards for Stormwater Management* manual (called the "Procedures and Design Standards Manual" in the remainder of this document).

Overview of the Pollutant Component

Excessive nutrient loading can lead to nuisance algae in both streams and lakes, leading to conditions that are unfavorable for supporting recreation and aquatic life and that can pose problems for public water supplies. The SET addresses this by calculating the total phosphorus and nitrogen load leaving a site before and after development, accounting for the influence of various BMPs used on the site. Protection of aquatic life and physical habitat is also a critical issue throughout streams in Macomb County, so the SET calculates upland sediment load in the same way as total phosphorus and total nitrogen. Pathogens increase risk of disease when people come in partial or full-body contact of surface waters, so the SET estimates *Escherichia coli* (*E. coli*) bacteria from storm event runoff. Total copper loads are also estimated as an indicator for metals. It is important to note that the SET does not include estimates of pollutant loading during the construction phase of a project; it assumes that development is completed and all bare soils are properly vegetated. All of the pollutant loading indicators and overall site hydrology are calculated on an annual basis using a modified version of the Simplified Urban Nutrient Output Model (SUNOM) developed by the Center for Watershed Protection (Caraco et al., 1998).

Baseflow loads are not included in the SET; while baseflow loads may be a significant fraction of a site's total load, they are highly variable and difficult to estimate. The focus of the Macomb County SET is to assess impacts to water quality from storm events and surface runoff, which can be addressed by BMPs. This is important to note when considering the impacts of *E. coli*. Michigan's water quality standards for *E. coli* are concentration-based, and include both high flow and low flow influences; while *E. coli* loading from storm events cannot be directly related to water quality standards, it does provide some useful information for understanding relative impacts of development and benefits of BMPs.

Parameters related to pollutant loading are detailed in Appendix A.

Overview of the Stormwater Criteria and Stormwater Credits Component

Development changes the hydrology of sites, with the potential for decreased infiltration, and increased runoff and peak flows. These changes often lead to streambank erosion and channel downcutting, causing impairment of physical habitat and biological communities. Two factors are especially relevant – peak flows in receiving streams during high volume storm events may increase substantially after a site is developed (due in large part to an increase in impervious surface) and the duration of time increases during which erosive flows take place. Macomb County's Channel Protection Criteria address runoff from storm events with a return interval of less than 10 years. While 2-year storms are not often considered for flood protection, these intermediate large storms represent a higher risk for downstream channel erosion. Very large storms (e.g., 10-year, 25-year) are highly erosive, but do not occur as often as the 2-year events. In addition, Macomb County's Water Quality Criteria provide a way to ensure BMP treatment capacity is sufficient to remove a significant fraction of pollutant loads generated on an annual basis.

The Procedures and Design Standards Manual includes several Stormwater Credits for the reduction of the required WQv and CPv treatment volume. These credits encourage innovative stormwater management that detains, infiltrates, and/or treats stormwater at its source. Centralized structures that collect and manage runoff from an entire site are often necessary and beneficial for flood protection and channel erosion goals, but practices that prevent, reduce, or slow stormwater runoff are often highly effective, and may ultimately reduce costs of conveyance structures and storage basins. Credits reduce WQv and CPv treatment volumes in a variety of ways. Some credits reduce volume by encouraging practices that substitute land covers which generate less runoff to begin with. Other credits directly manipulate the WQv and/or CPv calculations to reduce the required treatment volume.

How BMPs Are Addressed in the Pollutant Component

The SET allows the user to test how well various site designs that implement properly designed BMPs will perform with regard to mitigating changes in annual runoff/infiltration and pollutant loading. The model has built-in assumptions for infiltration/evapotranspiration and pollutant removal efficiency for various types of BMPs. It is important to note that the SET does not perform the engineering design for a BMP. Rather, the model assumes that BMPs will be designed according to specifications established by the governing authority.

There are many types of BMPs with flow control and pollutant removal capabilities. The majority of these BMPs fall into the following general categories: detention ponds/wetlands, open channels, filtering systems, and infiltration devices (Winer, 2000). These practices use a variety of techniques to reduce the impact of the increased runoff and pollutant loadings including reduction in flow velocity and quantity, runoff control, biological uptake, and filtration. BMPs vary in their ability to remove pollutants, and BMPs of the same type also vary in pollutant removal depending on their size, the quality of their design, and how well they are maintained over time. The SET has a menu of the most common BMPs used for water quality benefits. The terminology and pollutant removal efficiencies are taken from a number of information sources, some local to Michigan and some from national sources. BMPs included in the SET and their removal efficiencies are shown in Appendix B. More information about these BMPs is available in the Macomb County SET User's Manual and Guidance, and also the following local/regional sources:

- Macomb County's *Procedures and Design Standards for Stormwater Management* manual (Macomb County, 2008)
- Oakland County engineering design standards (Oakland County, 2007)
- Michigan Low Impact Development (LID) Manual (SEMCOG, 2008)
- Michigan Guidebook of Best Management Practices (Peterson et al., 1998)

2 Annual Pollutant Loads and Annual Infiltration and Runoff

The Site Evaluation Tool uses a modified approach based on the Simplified Urban Nutrient Output Model (SUNOM) developed by the Center for Watershed Protection (Caraco et al., 1998). Annual water balance and annual pollutant loads are calculated, and inputs include land use, annual precipitation and infiltration, soil hydrologic group information, event mean concentrations of pollutants by land use, and BMP pollutant removal efficiencies. Annual surface runoff is determined using the Simple Method (Schueler, 1987), which relates runoff depth to annual precipitation and the fraction of the area in impervious cover. The Simple Method can be rearranged to estimate runoff from pervious and impervious areas separately. Infiltration is calculated for pervious areas using area-averaged infiltration rates based on the soil type. BMPs that infiltrate water transfer surface runoff to infiltration. Annual loads for total suspended solids, total nitrogen, total phosphorus, total copper, and *E. coli* bacteria from storm event surface runoff are calculated for existing conditions, for the proposed site without treatment, and for the proposed site with BMPs.

Loads from surface runoff are calculated from the product of annual runoff depth, pollutant event mean concentration (EMC), and land area, and are determined separately for impervious surfaces, and natural and managed pervious areas. An EMC is the theoretical average pollutant concentration across large and small storm events over a long period of time. The BMP reduces the load based on the fraction of the runoff it treats and its removal efficiency (for removal efficiencies, see Appendix B).

The SET addresses loads from multiple land area types. This allows it to utilize EMCs from each type of land area. Data from a number of sources were used to fit estimates of distinct EMCs for two types of impervious surfaces (residential/office/institutional and commercial/heavy industrial) and six types of pervious surfaces (lawn/landscaping, grassland/meadow/savannah, forest/woods, wetlands, pasture [with livestock], and row crops). Ponds/open water surfaces (both natural and manmade), green roof surface area, and porous pavement surface area are also accounted for as land area.

2.1 HYDROLOGY

The model begins with an annual hydrologic balance relevant to the SET:

Equation 1.

$$P = R + E + I_{SW} + I_{BMP}$$

where
P = annual precipitation
R = runoff
E = annual evaporation and transpiration
I_{SW} = annual shallow groundwater recharge of stormwater
I_{BMP} = annual shallow groundwater recharge via BMPs

All units are in inches. Terms on the left side of the equation are inputs and terms on the right side of the equation are outputs. Evaporation is not calculated directly, but is accounted for implicitly. Each of the remaining terms is calculated and used for subsequent loading calculations. It is important to note that each of these calculations is performed separately for each land use/drainage area combination, and then summed to produce total runoff or load.

Runoff is calculated using the SIMPLE Method:

Equation 2.

$$R = 0.9 \times P \times \left(0.05 + 0.9 \frac{A_{imp}}{A_{tot}} \right)$$

where
A_{imp} = impervious area
A_{tot} = total site area

As the impervious fraction increases, runoff increases. The terms of the equation account for two aspects of annual runoff – that the majority of rainfall on pervious areas leaves the site as infiltration and evapotranspiration rather than runoff, while most of the rainfall on impervious surfaces becomes runoff. Runoff from each land use is treated separately in subsequent calculations, but the reported total site annual runoff is calculated using an area-weighted average. An adjustment factor was added to the runoff calculation for developed pervious land to account for soil compaction and the resulting increased runoff potential. The derivation of the adjustment factor is discussed in detail in Appendix A.

Stormwater infiltration is calculated as follows:

Equation 3.

$$I_{SW} = I_B m$$

where
I_B = annual base infiltration rate (in/yr)
m = multiplier based on type of surface

The base infiltration rate is related to the hydrologic group of the underlying soil. This ranges from a base infiltration rate of 18 inches per year for Group A soils to 3 inches per year for Group D soils. The multiplier is 0 for impervious surfaces (no infiltration), 1 for undeveloped land uses (full infiltration) or 0.8 for developed pervious land uses, which are generally compacted and have somewhat lower infiltration rates. An aggregate I_B is calculated based on an area average of the proportion of the site in each soil hydrologic group.

Infiltration through BMPs is calculated as follows:

Equation 4.

$$I_{BMP} = R \times f_s f_i$$

where
f_s = fraction of runoff in site reaching BMP
f_i = fraction infiltrated on an annual basis

BMPs influence annual hydrology by intercepting runoff and converting it to infiltration. The fraction of the runoff reaching the BMP is handled internally in the model by the assignment of land use to drainage areas. f_i is dependent on the type of BMP; most BMPs convert very little runoff to infiltration, but some are designed to store runoff and allow it to drain to the underlying soil. When there are multiple BMPs in a single drainage area, an aggregated f_i is calculated as detailed at the end of Section 2.2.

The influence of BMPs on annual runoff is also calculated. The runoff that BMPs trap may either leave through infiltration (f_i) or evapotranspiration. Note that the calculation is performed separately for each land use within each drainage area.

Equation 5.

$$R_{BMP} = R \times \left[1 - \left(f_i + f_e \right)\right]$$

where
R_{BMP} = adjusted runoff
f_e = fraction evaporated on an annual basis

The sum of f_i and f_e is the fraction of annual runoff entering a BMP that does not leave as runoff. The fraction that does become runoff is 1 minus the sum of f_i and f_e. Note that when there are multiple BMPs in a single drainage area, an aggregated f_e is calculated as detailed at the end of Section 2.2.

2.2 POLLUTANT LOADING

Terms not defined here are used in the previous section. Total loading is calculated as follows:

Equation 6.

$$L = L_R - L_{BMP}$$

where
L = total load
L_R = load from runoff
L_{BMP} = BMP load reduction

Loading from runoff is calculated as follows:

Equation 7.

$$L_R = RC_R A$$

where
C_R = EMC in runoff
A = land area

Since the runoff (as well as each of the other hydrologic terms) is expressed in inches, the product of runoff and land area produces runoff volume. The product of runoff volume and concentration results in an annual load.

The BMP load reduction is calculated as follows:

Equation 8.

$$L_{BMP} = L_R E_i$$

where
E_i = BMP pollutant reduction efficiency

BMP efficiencies are generally reported in research literature in terms of percent removal of annual load, so the load reduction is applied directly to the calculated annual load. Current model assumptions for BMP removal efficiencies and their sources are provided in Appendix B.

In cases where there are multiple BMPs utilized in the same drainage area (called a “treatment train”), E_i is calculated as follows:

Equation 9.

$$E_i = 1 - (1 - E_{i1})(1 - E_{i2})\ldots(1 - E_{iN})$$

where
N = number of BMPs in treatment train
$E_{i1} \ldots E_{iN}$ = Reduction efficiency for each BMP in the treatment train

For example, if the removal efficiencies of two BMPs in a treatment train are 45 percent and 35 percent, the overall removal efficiency of the treatment train is not 80 percent; rather it is 1 – (1 – 0.45)(1 – 0.35), or 64.25 percent. If the first BMP removes 45 percent, it passes 55 percent of the load. The second BMP treats 35 percent of the 55 percent remaining (19.25 percent), for a total of 64.25 percent. Note that the same calculation applies to f_i and f_e discussed in Section 2.1.

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3 Stormwater Criteria and Stormwater Credits

Macomb County's Procedures and Design Standards Manual specifies Stormwater Criteria requirements for protection of water resources and for meeting National Pollutant Discharge Elimination System (NPDES) Phase II stormwater regulations. The County has provided a set of unified BMP sizing criteria, which use a tiered approach for the protection of water resources. The criteria include:

- Water Quality, designed to protect and improve water quality
- Channel Protection, designed to reduce risk of downstream channel erosion
- Overbank Flood Protection, for reducing impacts of flooding
- Extreme Flood Conveyance to provide passage of very large storm events without damaging site stormwater infrastructure

Of these, the SET addresses the Water Quality Criteria and the Channel Protection Criteria. The specific requirements are:

- Water Quality
    - Treat the runoff generated from the site for a 1.0 inch rain event (WQv)
    - The maximum discharge concentration of total suspended solids (TSS) cannot exceed 80 mg/L
- Channel Protection
    - The volume from a 2-year 24-hour storm event must be stored and released over a minimum period of 24 hours (CPv).

The Procedures and Design Standards Manual contains further information about additional requirements and exceptions related to the criteria. Most are site or situation specific and are not addressed in the SET. However, one of the exemptions is included – the County waives the Water Quality Criteria if the site provides extended detention for the CPv. The SET implements the exception by providing a Yes/No select box; when the exemption is enabled, the **Model Output** worksheet in the SET does not display the WQv, but instead states that the requirement has been met.

3.1 Stormwater Criteria

The WQv is calculated using Schueler's Short Cut Method (Claytor and Schueler, 1996) as specified in the Procedures and Design Standards Manual:

Equation 10.

$$Rv = 0.05 + 0.009I$$

$$WQv = P/12 \times Rv \times A \times 43{,}560$$

where
Rv = runoff volume fraction
I = site percent impervious (0 to 100)
WQv = water quality volume (ft^3)
P = precipitation depth (P = 1 inch)
A = site area (acres)

Since P is fixed, the formula reduces to:

Equation 11.

$$WQv = 3{,}630 \times Rv \times A$$

The TSS maximum allowable discharge concentration is assumed to be equivalent to the weighted site EMC. The SET's calculation of sediment concentration differs somewhat from the one provided in the Procedures and Design Standards Manual, but the two methods are fundamentally similar since they are based on the same monitoring data (see Appendix A for discussion of Cave el al., 1994). The developer may elect to use either method for evaluation of compliance with the standard.

The SET calculates the weighted site TSS concentration as follows:

Equation 12.

$$C_{TSS} = L_T / R_T$$

where
C_{TSS} = site-weighted annual average discharge TSS concentration
L_T = total sediment load leaving site
R_T = total runoff leaving site

The SET calculation includes the combined effect of all the BMPs that reduce both load and runoff. The concentration is also shown for the post-developed site before BMPs are applied.

The CPv calculation is based on the NRCS Runoff Curve Number method (USDA, 1986). Table J-2 in Appendix J of the Procedures and Design Standards Manual provides a simplified approach to estimating CPv. The table lists Time of Concentration (*Tc*) ranging from 0.25 hour to 1.0 hour, and curve number (*CN*) from 70 through 98. Each combination of *Tc* and *CN* has a value for cubic feet per acre. The user must calculate a *Tc* and an area-averaged site *CN*. The CPv is the product of the ft^3/ac lookup value and site area.

The SET calculates the weighted site *CN* using curve numbers assigned to land use/HSG shown in Appendix A. HSG percentages are entered by the user for the entire site (not by specific land use) so the SET assumes the distribution of HSG is the same for all site land uses. The user may also specify a different weighted site *CN* if the SET curve number and HSG distribution assumptions are not correct for the site. Because the SET is not an engineering design tool, it does not estimate *Tc* so the user must provide it from outside calculations. The SET contains an internal copy of Table J-2, and performs the extrapolation based on the weighted site CN and Tc. The Procedures and Design Standards Manual includes a requirement that developed pervious land has the HSG class shifted one higher to account for soil stripping and compaction. The SET includes this adjustment in its calculation of weighted site CN.

3.2 STORMWATER CREDITS

Stormwater Credits provide an incentive for adopting practices that detain, infiltrate, and/or treat stormwater at its source. Both the WQv and CPv are potentially reduced, depending on the particular credit. Many of the Stormwater Credits encourage the use of alternative site configurations to reduce runoff and improve infiltration, such as decreasing impervious surfaces, and increasing forested and natural areas. Since the WQv and CPv are affected directly by the site's land cover and impervious area, the value of many Stormwater Credits is incorporated directly into the post-development site plan. No additional volume reduction is provided other than the inherent reduction associated with land surfaces that generate less runoff, or increase the *Tc*. The SET does provide a way to compare before-and-after WQv and CPv for two sets of post-developed land use, called the Pre-Credit and Post-Credit Proposed Land Use. The Pre-Credit land use represents the site that would have been designed if the designer was not influenced by the Stormwater Credits.

Many of the credits do manipulate the calculation of WQv and/or CPv, providing a reduction beyond a change in land use or *Tc*. For WQv, most take the qualifying credit land area and subtract from the *A* factor in Equation 11. A few of the credits subtract a fraction of the WQv based on certain criteria. For CPv, a few of the credits substitute a lower CN for the qualifying area.

There is a requirement that a given portion of the site can qualify for only one credit. This prevents double-counting, since many of the credits have similarities with each other. The following provides a summary of how the credits are implemented in the SET.

Credit 1: Impervious Cover Reduction Credit

WQv. Reducing impervious surface reduces the *I* factor directly in the WQv calculation. No additional reduction is given.

CPv. Reducing impervious surface lowers the weighted site *CN*. No additional reduction is given.

Credit 2: Redevelopment Credit

A site is considered either redevelopment or new development, never a combination of both. If a site qualifies for the Redevelopment Credit, then the entire site must be specified as qualifying for *Credit 2*.

WQv. The credit takes two tracks:

Is the post-developed impervious area reduced by 25% or more from the existing impervious area?

Yes

$WQv' = 0$

where WQv' = post-credit adjusted WQv

No

$C = I_p \text{ x } WQv_p$

$WQv' = WQv - C$

where I_p = pre-developed impervious cover
WQv_o = WQv for pre-developed site
WQv' = post-credit adjusted WQv

CPv. CPv = 0 unless a CPv was previously required at the site. If CPv was previously required, the SET refers the user to the County Engineering Department for consultation.

Credit 3: Waterway Buffer/Filter Strip Credit

WQv. The area specified for *Credit 3* is subtracted from *A* in the WQv calculation.

CPv. The area specified for *Credit 3* is assigned to the *CN* for "woods in good condition," using the appropriate post-developed *CN* for the site according to the HSG ratios entered in the SET.

Credit 4: Environmentally-Sensitive Development Credit

The entire site must be specified as qualifying for *Credit 4*. No other credit can be taken.

WQv. The WQv is set equal to 0.

CPv. The requirements of this credit limit impervious surface and require a significant portion of the site remain undeveloped, thus deceasing the weighted site *CN* and increasing *Tc*. No additional reduction is given.

Credit 5: Open Drainage Swale Credit

WQv. The area specified for *Credit 5* is subtracted from *A* in the WQv calculation.

CPv. Any changes in Tc would be included in the user's calculation. No additional reduction is given.

Credit 6: Conservation of Natural Areas Credit

WQv. The area specified for *Credit 6* is subtracted from *A* in the WQv calculation.

CPv. Increasing the footprint of natural, undeveloped area lowers the weighted site *CN*. No additional reduction is given.

Credit 7a: Reforestation Credit

Note that *Credit 7* in the Procedures and Design Standards Manual is split into *Credit 7a* and *Credit 7b* in the SET due to the difference in calculation for reforestation versus afforestation.

WQv. In the WQv calculation, 0.5 times area specified for *Credit 7a* is subtracted from *A*.

CPv. Increasing the footprint of the forest lowers the weighted site *CN*. No additional reduction is given.

Credit 7b: Afforestation Credit

WQv. In the WQv calculation, 1.5 times area specified for *Credit 7b* is subtracted from *A*.

CPv. Protecting forest from development lowers the weighted site *CN*. No additional reduction is given.

Credit 8: Impervious Surface Disconnection Credit

The Procedures and Design Standards Manual does not provide specific guidelines for calculating adjustments to the WQv. The amount of the credit will be decided by the County in consultation with the developer during the design review process. However, the SET allows the user to provide an educated guess.

WQv. The user enters an educated guess for the volume reduction (in cubic feet). An agreed-upon value can be entered during later stages of the design review process.

CPv. The Manual does not provide specific guidelines for calculating adjustments to the Tc. However, the user can make an educated guess in the calculation of Tc and confirm the value during the design review process. No additional reduction is given.

Credit 9: Permeable Pavers Credit

WQv. In the WQv calculation, 0.5 times area specified for *Credit 9* is subtracted from *A*.

CPv. No CN adjustment is provided for this credit. Any changes in Tc would be included in the user's calculation. No additional reduction is given.

Credit 10: Soils Preservation Credit

WQv. The area specified for *Credit 10* is subtracted from *A* in the WQv calculation.

CPv. Increasing the footprint of natural, undeveloped area lowers the weighted site *CN*. No additional reduction is given.

Credit 11: Green Rooftop Credit

Implementation. Green roof area qualifying for this credit is entered in the *Credit 11* column.

WQv. A qualifying site with a green roof will have a total exemption for the WQv. Note that the green roof must occupy a significant portion of the site's footprint. The designer would need to confirm whether the site qualifies for this credit with the County. If any green rooftop area is specified, the SET assumes the site qualifies for the credit.

CPv. The green rooftop area has an adjusted *CN* of 30 applied to it. Any changes in Tc would be included in the user's calculation. No additional reduction is given.

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Appendix A. Parameters for Hydrology and Pollutant Loading

See references below tables for data sources.

Table A-1. Infiltration Constants

Soil Type	Infiltration (in/yr.)	Data Source
A-Soil Infiltration	18	#1
B-Soil Infiltration	12	#1
C-Soil Infiltration	6	#1
D-Soil Infiltration	3	#1

Land Type	Infiltration Fraction	Data Source
Row Crops	1	#1
Pasture	1	#1
Forest	1	#1
Wetland	1	#1
Meadow	1	#1
Lawn	0.8	#1
Dry BMPs	0.8	#1
Porous Pavement	0	#7

Table A-2. Regional Rainfall Data

Parameter	Value	Data Source
Annual Rainfall (inches)	31.25	#2

Table A-3. Curve Numbers *

Land Cover	A Soils	B Soils	C Soils	D Soils
Agriculture, good hydrologic condition	67	78	85	89
Pasture, fair hydrologic condition	49	69	79	84
Wetlands	78	78	78	78
Grassland/Meadow/Savannah	30	58	71	78
Forest/Woods, good hydrologic condition	30	55	70	77
Lawn/Landscaping, good hydrologic condition	39	61	74	80
BMPs (Pervious Area, fair hydrologic condition)	49	69	79	84
Impervious Surface	98	98	98	98
Open Water (ponds/lakes, BMP pond area)	100	100	100	100
Porous Pavement	98	98	98	98
Green Roof	30	30	30	30

* Data Source: #3, except for Open Water data source #4

Table A-4. Event Mean Concentrations *

Land Cover	TN (mg/L)	TP (mg/L)	TSS (mg/L)	E coli (#/100 mL)	Copper (mg/L)
Pervious surfaces					
Agriculture	5.98	0.37	1,100	3,700	0.0045
Pasture (with livestock)	5.98	0.37	150	31,000	0.0045
Wetlands	1.38	0.08	30	330	0.0045
Grassland / Meadow / Savannah	1.74	0.11	51	330	0.0045
Forest / Woods	1.74	0.11	51	330	0.0045
Lawn / Landscaping	10.7	1.21	25	1,100	0.0045
Impervious surfaces					
Normal Traffic – all Residential/Office/Inst. + Commercial/Ind. rooftops	1.64	0.060	106	6,400	0.0395
High Traffic – all Commercial/Ind. except rooftops	1.55	0.169	87	1,800	0.0429
BMP surfaces					
BMP - Water BMPs (open water surface area)	1.31	0.09	7	1,800	0.0070
BMPs - Green Roof	1.64	0.06	106	6,400	0.0395
BMPs - Porous Pavement	1.64	0.06	106	6,400	0.0395
BMP – Pervious area	10.7	1.21	25	1,100	0.0045

Data Source: #5 and #6.

Derivation of Event Mean Concentrations

The Event Mean Concentrations (EMCs) from the Rouge River Project (Cave et al., 1994) provided an excellent foundation for deriving EMCs for the Clinton River SET (Tetra Tech, 2008b), which was used as the foundation for the Macomb County SET. The Rouge Project data were also utilized for pollutant parameters for the Clinton River HSPF Watershed Model (Tetra Tech, 2008a). However, the Rouge project did not measure bacteria, so *E. coli* EMCs in the SET were back-calculated from the HSPF model average buildup and washoff parameters, which were calibrated to local monitoring data. Copper was not modeled in the HSPF watershed model, so the Rouge copper EMCs were used solely for the SET.

Undeveloped Land Cover and Open Water Categories

For the most part, Rouge report EMCs were used for the SET EMCs for the following land covers: Agriculture, Pasture (with livestock), Wetlands, Grassland/Meadow/Savannah, Forest/Woods, and for the open water category. The Rouge report had a single category for Forest/Rural Open, which was used for both Forest/Woods and Grassland/Meadow/Savannah; there was also a single category for Agriculture/Pasture, so the same value was used for both SET categories with some exceptions.

EMCs for open water are based on atmospheric deposition wetfall data, also reported in the Rouge report. While most of a site's open water will likely receive runoff and pollutant loads from the surrounding area, water surface occupies space on a site and has loads associated with it, typically what is carried via atmospheric deposition.

Some modifications were made based on Tetra Tech experience with other EMC monitoring studies, many of which are summarized in Tetra Tech, 2004. The Rouge TSS EMC reported for agricultural areas was low (145 mg/L) compared to most other monitoring studies (on the order of 1,000 mg/L); the watershed area in the study was large, and was probably not reflective of surface runoff. The Agriculture and Pasture EMCs were instead taken from average values from the Clinton River HSPF model calibration for sediment in surface runoff. The Rouge Wetland EMC was also very low (6 mg/L), so the HSPF model average value was used in its place. For copper, the Rouge study reported 0 μg/L for Forest/Rural Open and Agricultural/Pasture, but cited a study where the concentrations "were assumed to be negligible." The SET instead used the same value as the Lawn/Landscaping category, developed using methods discussed below. Copper wetfall was reported and used in the SET for the open water category.

Developed Land Cover

For developed areas, numerical optimization was used to estimate the pervious versus impervious EMC separately. The SET requires mean surface washoff concentrations by land cover component, for which the observed EMC from a land use is separated into impervious and pervious fractions. An observed EMC represents the net surface runoff contributions of pervious and impervious surfaces in a given source area during a washoff event. The observed EMC can be written as a function of pervious and impervious EMC components as

Equation A-1 $$EMC = EMC_I \cdot F_I + EMC_P \cdot (1 - F_I)$$

where EMC_I and EMC_P refer to the EMCs for impervious and pervious surfaces, respectively, and F_I is the fraction of total surface runoff attributable to impervious surfaces.

One way to estimate the fractional distribution of runoff from impervious areas is via the SIMPLE model (Schueler, 1987), based on the rational formula. The SIMPLE Method formula can be expanded with the runoff depth, R, given by

Equation A-2 $$R = 0.9 \cdot P \cdot [0.05 + 0.9 \cdot Ia] = 0.9 \cdot P \cdot [0.05 \cdot (1 - Ia) + 0.95 \cdot Ia]$$

where P is precipitation and Ia is the fraction of area in impervious cover. This can be rearranged to express the fraction of surface runoff due to impervious surfaces as

Equation A-3 $$F_I = 0.95 \cdot {}^{Ia}\!/_{(0.05 + 0.9 \cdot Ia)}$$

Equation A-1 may be rearranged to yield

Equation A-4 $$EMC_I = \frac{EMC - EMC_P \cdot (1 - F_I)}{F_I}$$

Equation A-4 may then be used to express EMC_I in terms of EMC_P and the observed total EMC. Given total EMCs for multiple land uses this provides a basis for estimation of impervious and pervious EMCs.

Equations A-1 through A-4 present an approach for separating an observed EMC into pervious and impervious components. This suggests that these components can be resolved from optimization on reported data. Two approaches can be taken from this point. One would be to find optimal values of EMC_I and EMC_P across all EMC estimates for each individual land use. This approach is, however, unlikely to provide clearly resolvable estimates for the pervious and impervious EMCs. It is therefore preferable to assume that EMC values are constant across the pervious and impervious fractions of multiple related land uses, with differences in the observed EMC between land uses arising mainly as a result of differences in impervious surface coverage. The developed area EMCs in the Macomb County SET are therefore divided into three categories:

- Developed Pervious (comprised of the Lawn/Landscaping land use)
- Normal Traffic Impervious – all Residential/Office/Inst. land covers + Commercial/Ind. rooftops
- High Traffic Impervious – all Commercial/Ind. land covers except rooftops

The developed pervious EMCs are universal across land uses, but differentiating the impervious categories into normal traffic and high traffic allows a differentiation in loading rates among land uses.

The method was modified for the Macomb County SET to account for soil compaction during development that tends to increase developed pervious runoff. The adjustment was prompted by recent research conducted by Tetra Tech (2010b). The SIMPLE Method formula was empirically derived from a regression of runoff and impervious area. There is sufficient scatter in the data to introduce statistical error in the parameter that defines the regression line. The model is a good enough fit ($R_2 = 0.71$) to be useful for estimating runoff for urban developed sites, but is likely less reliable at the extremes. Since the optimization assumes pervious land is zero percent impervious, the runoff coefficient for 100 percent pervious developed land is only 4.5 percent of the annual rainfall. Wignosta et al. (1994) noted effective runoff coefficients for compacted pervious soils of 0.5, while Schueler (2001) suggested effective runoff coefficients for compacted urban soils should be in the 0.2 to 0.45 range. Pitt et al. (1999) also report a wide range of runoff coefficients for a limited suite of urban pervious soils in the Seattle area, with runoff coefficients for hydrologic soil group B (unamended) ranging from 0.5 to 0.26. Based in part on the reported ranges and the results of the optimization, the effective runoff coefficient in the optimization was adjusted to 20 percent.

<u>Sources</u>

1. Caraco et al., 1998.
2. Tetra Tech analysis of rainfall from nine gages throughout Clinton River Basin during 1994-2004. (Tetra Tech, 2008a.)
3. Sorrell, R.C., 2010.
4. Personal Communication. Robert Myllyoja, Staff Environmental Analyst, Hubbell, Roth & Clark, Inc., May 7 2010.
5. Analysis of Cave et al., 1994.
6. Analysis of buildup and washoff factors from Tetra Tech Clinton River HSPF Watershed Model (Tetra Tech, 2008a).
7. Best Professional Judgment

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Appendix B. BMPs and Efficiencies Used in Site Evaluation Tool

Table B-1. BMPs and Efficiencies Used in Site Evaluation Tool

Standard Removal Efficiencies	Efficiency (percent removal)					Annual Percent Infiltrated	Annual Percent ET
BMP	TN	TP	TSS	E coli	Copper		
Extended Wet Detention	31%	52%	80%	70%	57%	2%	5%
Extended Dry Detention	24%	20%	49%	88%	29%	15%	15%
Infiltration Basin	42%	65%	89%	90%	86%	40%	50%
Bioretention	55%	30%	74%	90%	97%	7%	35%
Sand Filter	32%	59%	86%	37%	37%	0%	0%
Infiltration Trench	42%	65%	89%	90%	86%	40%	50%
Vegetated Swale	56%	24%	81%	0%	65%	5%	5%
Bioswale	76%	46%	87%	0%	79%	10%	25%
Vegetated Filter Strip	56%	24%	81%	0%	65%	5%	5%
Dry Well	42%	65%	89%	90%	86%	40%	50%
Green Roof	0%	0%	0%	0%	0%	0%	50%
Porous Pavement	10%	20%	35%	37%	20%	10%	10%
Rain Barrels	4%	4%	4%	4%	4%	3%	1%
Cistern	15%	15%	15%	15%	15%	12%	3%
Hydrodynamic Device	0%	17%	43%	0%	23%	0%	0%
Catch Basin with Sump	12%	12%	20%	0%	12%	0%	0%

Sources and Discussion

The Center for Watershed Protection (CWP) has published a comprehensive review of BMP removal efficiency statistics in their National Pollutant Removal Performance Database. Version 3 (Center for Watershed Protection, 2007) adds 27 studies to the 139 studies reviewed in Version 2 (Winer, 2000). Version 3 provides a series of tables for types of practices, with each table showing removal rate statistics for several pollutants. The statistics shown include the median, minimum, maximum, 1st quartile, and 3rd quartile removal efficiencies, as well as the number of studies used to generate the statistics. The range of numbers and accompanying box and whiskers plots highlight the variability in performance for any given BMP. An example table is shown below.

Table 1. Dry Pond Removal Efficiency Statistics

	TSS	TP	Sol P	TN	NO_x	Cu	Zn	Bacteria
Median	49	20	-3	24	9	29	29	88
Min	-1	0	-12	-19	-10	10	-38	78
Max	90	48	87	43	79	73	76	97
Q1	18	15	-8	5	-2	22	1	83
Q3	71	25	8	31	36	42	59	92
Number	10	10	6	7	7	4	8	2

(Center for Watershed Protection, 2007)

BMP performance is variable for a number of reasons. Design standards differ from one locality to the next, as do treatment volumes. BMP designs have generally improved over time, but some of the original experimental BMP studies remain in the database. Local site conditions and pollutant loads are highly variable as well, even within the same watershed.

When evaluating a site's performance, it is important to realize that the removal efficiencies reflect central tendencies, but that the site's individual performance may be poorer (or perhaps better) than the removal efficiency indicates. Removal efficiencies themselves are inexact, and have a high degree of uncertainty. Many of the median removal efficiencies for popular BMPs have changed over time as the CWP database has added studies.

The pollutant removal efficiencies used by the Macomb County SET are largely based on median values from Version 3 of the CWP database. Some BMP types are not included in the database, so other studies were used when necessary. Annual hydrology performance (annual percent infiltration and annual percent evapotranspiration, or ET) are based on a number of sources and best professional judgment.

Extended Wet Detention

Pollutant removal is set equal to the median removal for the *Wet Pond* practice in the CWP database. Annual hydrology is based on Strecker et al. (2004), who reported on mean outflow to inflow ratios for several types of practices. They found a 7 percent reduction in flow for wet retention ponds; best professional judgment was used to apportion it to 2 percent infiltration and 5 percent ET.

Extended Dry Detention

Pollutant removal is set equal to the median removal for the *Dry Pond* practice in the CWP database. Strecker et al. report a 30 percent reduction in annual runoff; while this may seem high, it is likely that the grass-lined basin is absorbing the runoff from smaller storms and infiltrated/transpiring it. Best professional judgment was used to split the 30 percent equally between infiltration and ET.

Infiltration Basin, Infiltration Trench, Dry Well

There was not enough data to differentiate between these practices, so they were all assigned the same performance. Pollutant removal is set equal to the median removal for the *Infiltration* practice in the CWP database. Bacteria removal was not reported; assuming that the practices are sized to capture and infiltrate 90 percent of the annual runoff, a 90 percent removal rate for bacteria is assumed. Annual hydrology is also based on an assumed 90 percent reduction in annual runoff, which is assigned to 40 percent infiltration and 50 percent ET. The ET value was set high because a large fraction of the infiltrated runoff will become interflow and replenish the shallow plant rooting zone in the soil.

Bioretention

Pollutant removal is set equal to the 3rd quartile removal for the *Bioretention* practice in the CWP database. The median removal rates in the database are lower than many other monitoring studies indicate (Hunt et al., 2006, Hunt and Lord, 2006). Bacteria removal was not reported, so 90 percent removal was selected based on an assumed treatment of 90 percent of the annual runoff. Annual hydrology is based on the work of William Hunt (North Carolina State University, 2004, personal communication).

Sand Filter

Pollutant removal is set equal to the median removal for the *Filtering* practice in the CWP database. Since most sand filters are housed in concrete structures, the annual hydrology effects are assumed to be negligible.

Vegetated Swale and Vegetated Filter Strip

Pollutant removal is set equal to the median removal for the *Open Channel* practice in the CWP database. The database reported negative removal for bacteria (though only three studies were available). While it is possible that channels and filter strips are a bacteria source if frequented by waterfowl, it is also likely that some removal should take place. The SET is also not configured to calculate negative removal, so 0 percent was used for bacteria. Best professional judgment was used to assign the annual infiltration and ET factors.

Bioswale

This design is essentially grass-lined bioretention in an open channel. The bottom of the swale is dug out and filled with a permeable soil mix (like bioretention), and the swale itself is graded with check dams and/or raised culverts to create a ponding area, which is filtered and treated by the soil media. It should perform better than conventional swales, so the 3rd quartile pollutant removal for the *Open Channel* practice in the CWP database is used. As before, 0 percent removal was used for bacteria rather than a negative removal rate. Annual hydrology is assumed to be similar to bioretention; infiltration is set 3 percent higher (more contact area due to the elongated shape), but ET is 10 percent lower (grass is not as effective as shrubs or trees in bioretention).

Green Roof

Green roof performance was not reported in the CWP database. Moran et al. (2003) report mixed results in early years of green roof monitoring for sediment and nutrients; green roofs typically export nutrients during the establishment phase for vegetation. Since green roofs receive minimal loads (atmospheric deposition, mostly), and slow-growing desert plants (sedums) are used at most installations, a 0 percent removal is assumed for all pollutants (export = input). Moran et al. had more consistent results for annual hydrology; as much as 60 percent of the annual rainfall was stored and evaporated from the green roofs. In the SET, 50 percent is used as a conservative estimate.

Porous Pavement

Porous pavement performance was not reported in the CWP database. Collins et al. (2007) report mixed results, as do Bean et al. (2007). Bean et al. report nutrient removal for installations in sandy soils that support infiltration, although percent removal is not reported. The pollutant removal rates reflect best professional judgment of a review of these studies, but with the caveat that there is a great deal of uncertainty associated with them. Porous pavement that supports infiltration is likely to perform well if the underlying soils have high infiltration rates, less well if the soils have poor infiltration rates, and poorly if the installation has an impermeable liner. Annual hydrology effects reflect best professional judgment for installations supporting some infiltration.

Rain Barrels and Cisterns

The effects of these practices are difficult to assess, and are entirely dependent on how the stored rainwater is used and how much of it is used. The annual hydrology and pollutant removal estimates are based on an analysis performed by Tetra Tech for the Orange Water and Sewer Authority in central North Carolina (Tetra Tech, 2006). The analysis used the North Carolina State University Water Harvesting Model (available at http://www.bae.ncsu.edu/topic/waterharvesting/), which performs a daily simulation of rainfall and water use driven by 30 years of regional precipitation data. The model has many inputs, including region, roof size, common water uses and separate related inputs, and storage volume. The analysis estimated the percentage of total roof runoff volume diverted to irrigation use. It is important to note that these are simply estimates, and could be significantly different depending on the number and size of rain barrels or cisterns used, and the water consumption pattern.

Hydrodynamic Devices

A Tetra Tech analysis of the International Stormwater BMP Database (Geosyntec Consultants and Wright Water Engineers, Inc., 2007) estimated the median pollutant removal performance. The analysis showed export for nutrients, so the removal rate was set to 0 percent for TN and TP. Annual hydrology effects are assumed to be negligible.

Catch Basin with Sump

Many commercial and proprietary products are on the market today, each with claims of outstanding sediment removal. For instance, the Stormceptor® (according to its website) claims an 80 percent removal of suspended solids. In independent tests, Waschbusch (1999) and Clausen et al. (2002) both reported only 25 percent removal of sediment. In a study of a number of practices tested along Interstate 93 in Boston, Massachusetts, USGS reports 39 percent of sediment removal in a deep-sumped hooded catch basin during a 14-month monitoring period (Smith, 2002). The Stormwater Manager Resource Center (http://www.stormwatercenter.net/) cites two studies for catch basins with sufficient data, one from 1997 showing 32 percent TSS removal, and another from 1982 with TSS ranging from 10 percent-25 percent, and TP ranging from 5 percent-10 percent. Environmental Consulting & Technology, Inc. (2005) studied several catch basin inserts in St. Clair Shores, Michigan; the control site with a sump but no insert showed 0 percent mass removal of sediment. To be effective, the sump must be emptied on a regular, frequent basis. The maintenance interval may vary depending on the characteristics of the contributing drainage area (for instance, use of road sand may fill a basin more quickly). Mineart and Singh (2000) determined that the greatest amount of sediment reduction could be achieved with monthly cleanout of sumps (three to five cubic feet); less frequent intervals (quarterly through annual) reduced the sediment recovered by a large margin (0.8 to 2.5 cubic feet). Based on a synthesis of the cited studies, a TSS removal rate of 20 percent was assumed, and nutrient/copper removal was assumed to be 12 percent (bacteria removal is assumed to be negligible). Very little information is available about nutrient or metals removal, so best professional judgment was used to estimate these rates. Sediment sorption is the only likely removal mechanism, so TP, TN, and copper removal were set proportionately low.